BETT TTEB

The Effects of Re-Insulation on 8 Houses in Ottawa

A RESEARCH REPORT

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A Study of Eight Older Houses in Ottawa that have been Retrofitted by the Addition of Loose-Fill Insulation to the Walls

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ABSTRACT/RESUME

Experimental measurements have been conducted on eight houses in the Ottawa area to study the changes induced in house performance when loose-fill insulation is installed in walls. The report presents details on the induced changes in furnace performance, house airtightness, temperatures, humidity levels and position of the neutral pressure plane. ECAP auditing procedures were applied to the houses, and the predicted fuel consumptions showed a considerable disagreement with actual values.

* * *

Des relevés ont été effectuées à titre d'expérience dans huit maisons de la région d'Ottawa en vue d'étudier les changements survenus par suite de l'installation de matériaux isolants en vrac dans les murs. Dans le rappoort, on donne des précisions, sur les changements survenus, notamment en ce qui a trait au rendement de la chaudière, à l'étanchéité de la maison, aux températures, aux niveaux d'humidité et à l'emplacement du plan de pression neutre. Dans ce cas, on a utilisé les méthodes de vérification, du P.A.E.E., et les prévisions en matrière de consummation de combustible ont permis de relever des écarts considérables par rapport aux valeurs réelles.

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* The appendices consist of basic data and field reports, and are contained in a second volume which can be obtained from EMR on request.

When retrofit work is conducted on a house it may indirectly affect several aspects of the house performance. In some instances this may be advantageous, but in others it may be harmful. Interactional effects may therefore be an important part of retrofit design, but they have not been investigated to any significant degree to date.

Two parallel studies have been conducted to quantify the secondary effects of wall re-insulation: one in Winnipeg and one in Ottawa, to give some coverage of climatic variations. The main objectives were to investigate the effects of wall re-insulation on house infiltration performance, furnace performance and humidity levels. Significant changes were observed in each of the studies, but the sample sizes were not large enough and the experimental work was not extensive enough to allow precise quantification of the effects - for general application.

The significance of these two studies is that they confirm the existence of these secondary effects. In general, the secondary effects of wall re-insulation, of the type covered in the studies, was not large. However, it is reasonable to assume that the magnitude of the secondary effects will increase with the extent of the retrofit work. Thus re-insulation with rigid insulation sheathing, for example, might produce greater secondary effects and would possibly merit investigation.

This report deals with the study on houses in Ottawa. The parallel study is covered in another report in this same series, entitled "The Effect of Re-Insulation on Some Houses in Winnipeg."

The report falls in the category of Low-Rise Residential buildings - a category that is managed by Saskatchewan Research Council under contract to EMR.

The purpose of this report is to contribute to an improved understanding of the full impact of wall reinsulation on the Canadian housing stock. Due to the preliminary and limited nature of the investigation, the report does not aim at providing final conclusions. The emphasis is, instead, on documenting important learning experiences, clarifying key issues which require further research and contributing to the evolving state-of-the-art of retrofit performance testing.

Reviewers should also be aware of a number of factors which constrained the design and execution of the study:

1. Project deadlines were very tight. From start to finish, the project was completed within 9 1/2 weeks (not including report writing).

2. Availability and range of sample homes was quite limited, since the study relied on the voluntary and unpaid participation of householders and insulation contractors.

3. The housing sample was further constrained because the study had to be executed during the February and March period, when very little reinsulation work is taking place in Ottawa. (Many insulation companies close their office during this period due to lack of work.)

4. The study involved a number of test procedures and tools which were unfamiliar or untried. As the result, the development and adaptation of the test methods themselves became a major concern and also a key constraint within the short time-frame of the study.

5. A key objective of the study was to monitor energy consumption before and after insulation. Work in this area was hampered by the unpredictable and often warm March weather.

For these reasons, study findings are often inconclusive and at times, incomplete. Consequently, while the results are instructive, it would be unwise to draw final conclusions from the data presented herein.

The report does not necessarily reflect the views or policies of either Energy, Mines and Resources Canada or Saskatchewan Research Council. The publication of the report has been approved by these two agencies because, in their opinion, it satisfies the requirements of the Buildings Energy Technology Transfer Program and advances the state of the art of residential energy conservation.

D. Eyre
Saskatchewan Research Council

May, 1983.

ACKNOWLEDGEMENTS

This study was a team effort; and the team deserves mention.

Assistance with management, data analysis and energy auditing components was provided by Ron Argue.

Field testing of houses, and data preparation, was conducted with assistance from engineering and building scientists on Retrospectors' staff, especially Bill Semple, Jim Smith, and Don Fugler.

Des relevés précis ont été effectués à partir d'un échantillonnage restreint de maisons dans la région d'Ottawa en vue de déterminer les différents changements constatés et imputables à la réfection de l'isolation thermique. Cette recherche s'est limitée aux maisons dont l'isolation thermique avait été refaite à l'aide de matériaux isolants en vrac dans les murs extérieures. Le facteur temps, de même que d'autres éléments, ont limité les recherches à huit maisons.

Les relevés expérimentaux ont été effecctués avant et après les travaux de réfection. Les facteurs mesurés comprennent entre autres:

- le rendement de la chaudière
- l'étachéité de la maison
- l'emplacement du plan de pression neutre
- les températures intérieures et l'humidité
- la constante de temps thermique de la maison, obtenue à partir d'un régime transitoire de refroidissement.

On a observé une amélioration marquée des niveaux d'étanchéité et d'humidité après les travaux de réfection de l'isolation thermique, bien que les températures de la surface des murs intérieures et l'emplacement du plan de pression neutre soient restés les mêmes.

La réduction de la consommation d'énergie des chaudières était de l'ordre de 6 à 30%, après correction pour tenir compte des variations de température ambiante. Le cycle ponctuel moyen des chaudières a été considérablement diminué après les travaux de réfection, et l'efficacité thermique en régime permanent n'a pas semblé être modifiée de façon marquée.

La constante de temps thermique, déterminée d'après un régime transitoire de refroidissement, s'est généralement accrue après les travaux, et cette augmentation proportionnelle a varié de façon considérable d'une maison à une autre.

Les analyses du bilan énergétique des huit maisons ont été exécutées à l'aide de la méthode du P.A.E.E. Fait intéressant à noter, cette méthode a permis d'établir des prévisions de consommation de combustible de 100% à 200% supérieures à la consommation mentionnée sur la facture de chauffage.

1.1 Background

An extremely rapid growth in the reinsulation industry in Canada over the past 7 years is bringing about unprecedented modifications to our existing housing stock.

In hindsight, it is clear that such a massive investment in property should have been preceded by careful field research, and accompanied by continuous on-site evaluation. In this way it would have been possible to build confidence in the marketplace, to avoid serious building maintenance problems, to protect the health and safety of residents, to train and regulate the industry, and to constantly improve the cost-benefit ratios by clarifying investment priorities and perfecting technical procedures.

Unfortunately, there has been little field research to date. And the little we know about the actual performance of older houses often contradicts the conventional wisdom. Actual energy savings are sometimes lower than predicted, air leakage is very much a large unknown, there may, or may not be an important relationship between the overall thermal resistance of a building and the efficiency of the heating system, the risk of moisture problems in walls may outweigh any potential benefits from reinsulation, the impact of reinsulation upon the building environment is not well understood, and the list goes on and on.

In fact, there are so many unanswered questions about reinsulation of homes, that our first priority is the development of more efficacious techniques for inspecting, monitoring and diagnosing the energy performance of buildings. In addition, we urgently require more investigation of the real impact of reinsulation work currently under way in Canadian cities. The field research must be quick, clear and multi-purpose in nature, and be part of a well integrated and coordinated strategy to investigate residential energy conservation priorities.

With this in mind, Retrospectors has undertaken the current wall reinsulation study as part of the low-rise residential sector of the Buildings Energy Technology Transfer program.

Careful measurement of the effects of wall reinsulation is particularly important, since it is an increasingly common retrofit measure which entails considerable costs and potential risks for many Canadian householders.

1.2 Objectives

In an effort to address the need for more comprehensive field research on the implications of the home retrofit industry, this project is designed with four key objectives in mind. These are as follows:

1. To measure empirically the energy savings resulting from typical wall reinsulation work in older housing stock.

2. To determine the impact of reinsulation work on other aspects of building performance: specifically, air tightness, humidity, comfort, furnace operation, and air pressures across the building envelope.

3. To evaluate and compare various techniques for predicting and measuring energy savings associated with reinsulation, with a view to improving understanding of priorities and problems in home retrofit and to facilitating the work of various standards working groups.

4. To identify common deficiencies and other problems in wall and attic reinsulation work.

1.3 Study Design

Eight houses in the Ottawa area were selected by Retrospectors and subjected to continuous energy and humidity monitoring and a series of comprehensive building performance tests before and after reinsulation work. (Householders covered all reinsulation costs.) All houses were subjected to wall reinsulation, and, in three cases, attic reinsulation as well. Reinsulation work employed local

insulation contractors using cellulose or glass fibre fill insulation. Event recorders were used to chart furnace on-time and cycling throughout the test period. Householders recorded daily temperature and humidity from thermohygrometers.

The 'before' and 'after' tests on the houses included measurements of indoor surface and air temperatures, airtightness measurements, a thermographic scan, a comprehensive energy audit and building inspection, an approximate location of the neutral pressure plane around the building, and a decay heat loss test for determining energy time constants.

2.1 Findings

The constraints imposed upon this study did not permit a conclusive evaluation of the thermal performance of houses undergoing wall reinsulation. Instead, the focus was on defining the scope of the task and developing an appropriate research design. However, the before-and-after tests on eight reinsulated houses has provided a basis for a number of general observations:

1. Wall insulation coverage in the houses was generally good. A number of voids were caused by typical structural features in the houses that had been missed or ignored by installers. There were no significant variations in quality between contractors or between different insulation materials.

2. There was a considerable amount of air leakage occurring throughout these houses before and after insulation, with no discernible change in distribution. All houses could have benefitted from caulking and sealing -- wall cavities and floor cavities function as large conduits for air flows into and out of the house.

3. The Equivalent Leakage Area (ELA) of the houses was significantly reduced as a result of the wall reinsulation, and the houses became less susceptible to low pressure air leakage.

4. The indoor relative humidity and temperatures remained fairly constant over the testing period and corresponded well with the estimates based upon initial measurements and discussions with householders. Relative humidity did tend to rise slightly in most houses following reinsulation, and increased considerably in those houses where moisture production and indoor humidities were already above average.

5. Wall surface temperatures in the houses are highly dependent on wind speed, gravity convection and air leakage patterns. In some cases, the additional wall insulation produced no discernible effect on wall surface temperatures.

6. The neutral pressure plane on the two and two-and-one-half storey houses is located approximately at the top of the 2nd floor windows, both before and after insulation. Changes in wind direction did not significantly alter the plane during cold weather.

7. The energy time constant (cooling) for the uninsulated houses is typically very long, in the range of 20 to 30 hours. There was a noticeable although extremely varied, lengthening of the time constant following reinsulation.

8. Monitoring of furnace operation before and after reinsulation showed a reduction of 6 to 30% in energy consumption, corrected for ambient temperature variations. For accurate estimates of energy savings, furnace monitoring must incorporate thermostat control of indoor temperatures and a control sample that is carefully selected and operated.

9. The average continuous run-time of furnaces was shortened considerably following reinsulation. Furnaces were grossly oversized both before and after reinsulation. The shorter furnace run times were largely a result of reduced cooling of thermal mass within the house during night-time setbacks and a consequently shorter warm-up period.

10. Furnace steady-state efficiencies did not change significantly throughout the test period, but after a thorough cleaning and instrumented tuning, all the units showed a considerable improvement in efficiency.

11. Estimates of heating costs for older houses, based upon theoretical RSI values and infiltration rates, were typically 100 to 200% larger than estimates based upon actual fuel records.

2.2 General Recommendations

In future studies, where the primary objective is to optimize the thermal performance of housing, consideration should be given to a reasonable period of planning and research design prior to any large scale field testing. The use of pilot studies or trial runs is a useful approach that worked very well in this project.

As a means of focusing the research and streamlining the presentation of results, the project design should clarify the information strategy for transferring knowledge to each of the following groups:

- persons involved in policy and program development who require a better understanding of the overall impact of various retrofit procedures;
- persons engaging in the design and production of technology for testing, retrofitting or operating homes;
- householders interested in guidelines for energy management and retrofit opportunities;
- tradespeople in related occupations, especially those who are attempting to innovate and pioneer new services to householders;
- technicians, engineers, research scientists and other members of the building performance testing community.

In cases where research on housing is undertaken in areas that are of wide concern, the project should also incorporate the necessary funding and contractual obligations to ensure that the field contractor will fully document the choice of equipment, test procedures and learning experiences.

2.3 Specific Recommendations

A number of specific recommendations have been listed below. They are based upon the experience of studying wall reinsulation performance in the Ottawa area, and are intended to guide future activities in this area.

1. The development of cost effective, engineering level techniques for monitoring energy consumption in older homes is a project that requires a time horizon sufficient to permit the honing of test procedures. A wide sample of houses is required to ensure applicability, and an integrated test procedure must be employed that can compare the value of various techniques, without distorting the actual results of reinsulation or other energy conservation measures.

   With these points in mind, it is clear that such a project would be of great benefit. The first step would be to produce a document that critically reviews each of the prime alternatives, describes the learning experiences of previous projects, presents a detailed, step-by-step test procedure for each major type of building, and directs the reader to sources of appropriate technology and literature. Only with such an overview will there be a basis for an evolving expertise within the industry, or for a comparison of test results between regions.

2. This study attempted to follow precisely the procedures contained in two CGSB standards for performance testing of houses (thermographic and airtightness).In both cases, the condensed language of the standard made it difficult to appreciate the rationale for the procedures, especially where special circumstances indicated that contrary measures might be more appropriate.

   The members of standards working committees should encourage the organization to publish a companion document to provide the latest arguments for each section of the standard. Without the background document, new members, or the community at large,

will not be likely to fully appreciate and/or adopt the standard, especially in the buildings area, where there is so much flux and controversy.

3. The majority of older houses in the Ottawa area are being insulated by removing one brick at the top of a two-storey stud space, and filling the whole cavity with a direct blow method. The packing will not be even throughout the cavity, and a possibility exists that the insulation will split, pull away, or settle in various locations. Additional thermographic investigation is warranted, to identify such failures at one or two-year intervals.

4. Further work, in the area of insulation evaluation with thermography, should involve more follow-up analysis on-site. Fibre optics could be used to actually inspect the void without damage. Where houses with insulated walls are being renovated, it may be possible to actually remove wall finish and visually record the problem, using thermograms, graphics and colour slides.

5. There is a need to complete and document a thorough comparison of low cost and high cost thermographic imaging devices. Contractors require guidance on whether the more affordable equipment is adequate for the evaluation of air leakage and wall insulation, particularly when used in conjunction with a door fan.

   The use of the door fan with thermography for interior scans of housing should be considered by the CGSB Thermographic Working Group and the appropriate additions and revisions made to the standard.

6. This study has succeeded in demonstrating that reinsulation of older, conventional housing stock will reduce the equivalent leakage area. Future evaluations of energy savings from insulation should involve several control groups to differentiate the relative savings from air sealing of houses prior to and following the reinsulation. Otherwise, the effect of insulation on air tightness may serve to confuse the data or lead to false conclusions.

7. There is a need to institute continuous monitoring of air change and indoor humidities in houses before and after wall insulation in order to clarify issues raised by this study.

8. Householders require simple guidelines or perhaps a sample contract for wall reinsulation jobs, so as to assist them in obtaining comprehensive services. The guidelines could include such items as:

   - the pros and cons of filling walls from the outside, inside or from up in the attic;
   - special construction features and how they should be insulated;
   - other areas of the house that can be blown with insulation or "touched up" at the same time as the main walls;
   - typical adjustments to heating systems after wall insulation (downsizing, balancing, duct taping, longer set-backs);
   - air sealing wall cavities;
   - ensuring fresh air and humidity control.

9. There is a need for a more detailed analysis of how air moves through insulated and uninsulated wall cavities of houses under various wind, temperature and operating conditions. Continuous monitoring of flows and temperatures is required in a number of intermediate floor and wall locations. It may be the case that wall insulation jobs should include insulation of some floor and partition cavities, or that urethane foaming kits should be first used to seal the exterior cavities from the adjacent cavities.

10. Decay heat loss tests should be conducted on a representative sample of older housing over a full year in an attempt to better understand the sensitivity of the test, to streamline measurement and calculation procedures, to document the preferred techniques, and

to evaluate the technique as a performance test for retrofit housing.

11. The accuracy of energy audit predictions is highly dependent on the estimation of correct RSI values for the main walls. The effective resistance values of walls in houses must be better understood if current energy auditing methods are to accurately predict fuel bills and savings. To what extent are the values affected by insulation materials, structural materials, depth of cavity, humidity, wind speed, air leakage and stratification? Is it possible to measure the average RSI values, or to predict the thermal resistance of wall components over a typical heating section?

The approach to house selection was to choose typical homes, typical insulation materials, and typical insulation applications. For these reasons, an effort was made to screen houses prior to selection and then to minimize any influence from the study on the type and quality of insulation work performed.

3.1 Prerequisites for House Selection

The essential requirements for houses participating in a project are listed below:

1. the householder must be willing to insulate the walls, or the walls and attic of the house at their own expense and at a time chosen by the research team;

2. the householder must be willing to allow access to the house by technicians, both before and after the insulation work, for purposes of energy monitoring and building performance testing;

3. the occupants of the house should maintain a fairly regular and consistent lifestyle and indoor environment;

4. the house should be a single detached dwelling or side-by-side of not more than three stories;

5. the house should be heated solely by a forced warm air furnace;

6. no other retrofit work must be undertaken by the householder during the test period and for a period of 12 months following the test period;

7. the insulation work will not be accompanied by any amount of air-tightening work;

8. the insulating material will be blown loose glass fibre, cellulose or rock wool (as determined by householder or contractor);

9. the insulation will be applied to above grade walls only and also to the attic if so desired by the householder; and

10. there should currently be no insulation in the main walls of the house.

3.2 Description of Houses

Detailed information on all of the test homes is contained in Table 1.1 and 1.2. In several instances, the houses did not meet all of the prerequisites of the study. It was not possible to be more selective due to the limited number of candidates.

The Waverley and Shakespeare houses were both heated with hot water systems, which made the energy monitoring data somewhat more difficult to interpret and to compare with other houses. The Besserer house was a complex space heating system, incorporating a passive solar addition, an air-tight woodheater, a new gas furnace, and several forced air heat distribution systems.

3.3 Negotiations With Householders

Householders were initially approached through the media and encouraged to enquire about the research project. Media coverage included radio interviews, feature newspaper articles, advertisements, and a four-minute slot on the local television news. Sample promotional material is included in Appendix 9.

TABLE 1.1 BUILDING DESCRIPTIONS AND ENERGY DATA

TEST HOUSE	WAVERLEY	McLAREN	FIFTH	SHAKESPEARE
TYPE	Semi-Detached	Single	Semi-Detached	Single
AGE	Pre 1920	Pre 1920	Pre 1920	Pre 1920
NO. OF STOREYS	2-1/2	2-1/2	2	2
FUEL	Oil	Oil	Oil	Oil
HEATING SYSTEM	Hot water	Forced air	Forced air	Hot water
AREAS INSULATED	Walls	Walls	Walls/Attic	Walls/Attic
INSULATION	Cellulose	Glass Fibre	Cellulose	Cellulose
AREA INSULATED (m^2)	151^2	225^2	106^2	150^2
ENVELOPE AREA (m^2)	543	527	373	381
ABOVE GRADE AREA (m^2)	376	363	240	225
VOLUME (m^3)	790	706	500	307
HEAT LOAD ESTIMATE (W/°C) (ASHRAE)	690	938	394	488
FUEL CONSUMPTION (Litres/D.D.)	.91	1.10	0.57	.79
PROJECTED HEAT COST 1982/83 (W/O INSULATION) ($) (FROM FUEL CONSUMPTION)	1287	1525	840	1100

TABLE 1.2 BUILDING DESCRIPTIONS AND ENERGY DATA

TEST HOUSE	THIRD	BESSERER	SECOND	STRATHCONA
TYPE	Single	Single	Single	Semi-detached
AGE	1920-45	Pre 1920	Pre 1920	Pre 1920
NO. OF STOREYS	2-1/2	2	2	2
FUEL	Oil	Gas	Oil	Oil
HEATING SYSTEM	Forced air	Forced air	Forced air	Forced air
AREAS INSULATED	Walls	Walls	Walls/Attic	Walls
INSULATION	Glass Fibre	Cellulose	Glass Fibre	Cellulose
AREA INSULATED (m^2)	150	145	140	60
ENVELOPE AREA (m^2)	398	478	387	310
ABOVE GRADE AREA (m^2)	267	290	240	180
VOLUME (m^3)	543	531	432	328
HEAT LOAD ESTIMATE (W/°C) (ASHRAE)	486	484	440	394
FUEL CONSUMPTION RATE (Litres/D.D.)	.56	.23	.63	.69
PROJECTED HEATING COST 1982/83 W/O INSULATION ($) (FROM FUEL CONSUMPTION)	830	355	899	978

As an incentive to participate and cooperate, the householders were offered an energy audit package, a summary of all results (except thermography) to be delivered at the completion of the project, and a comprehensive furnace servicing and tuning. Furnace servicing was conducted at the same time as the burner mechanic removed test equipment at the completion of furnace on-time monitoring.

After several weeks of rather low response to media advertisements, it was felt necessary to approach insulation contractors directly. Two of the largest contractors in the Ottawa area tried very hard to find additional test houses, but without much success. It was too late in the season. Even householders who were agreeable to the idea were in a great rush to insulate before the weather became any warmer.

Ultimately, eight homes were selected. A signed agreement was obtained from each householder outlining terms for participation. A sample agreement is included in Appendix 9. The agreement covered access to the home when required, liability, contracting and payment for specified insulation work, installation and removal of monitoring equipment, recording indoor humidities, and access to fuel consumption records and other information relevant to energy auditing.

A thermographic scan was conducted on the interior of all test homes, both before and after the wall reinsulation. An AGA 750 camera was used for this purpose. During the scan, a door fan was used to ensure the house remained under a constant negative pressure of approximately 35 Pascals. Hardcopy visual and thermographic images were recorded of specific site anomalies.

The scanning was conducted according to the Canadian General Standards Board provisional standard 149-GP-5MP[1]. An exception was made in the case of section 3.4.2 of this standard, which requires that buildings with brick veneer not be subjected to direct solar radiation for a period of 8 hours prior to the scan. Although portions of the south facing wall were occasionally exposed to direct sun, the effects were not felt to be detrimental, especially due to the large temperature and pressure differences across the envelope.

4.1 Results

The post-insulation thermographic investigation revealed a number of typical wall insulation voids in the test houses. These voids are illustrated in the detailed site reports for each home (Appendix 1). A summary of the most typical kinds of problems, and an explanation for their occurrence, is contained in Table 2. Some additional highlights are presented below.

1. Both the pre-insulation and post-insulation scans indicated considerable amounts of air leakage into the wall cavities -- partition walls and exterior walls. Streaks of cold infiltration, stretching one to two metres, were common, both at the top and bottom of the walls. The infiltration into the wall cavities was usually accompanied by similar (or colder) infiltration patterns into the inter-floor joist spaces.

2. The pattern of air leakage into cavities, and into the living areas of the houses, did not appear to change significantly following reinsulation work. The leaky areas around trim work, floors and wall cavities remained leaky. Because thermography is primarily a

TABLE 2: TYPICAL WALL INSULATION DEFECTS IDENTIFIED WITH THERMOGRAPHY

LOCATION	EXPLANATION	IDENTIFICATION
Above large windows and first floor doors	Diagonal cross bracing and/or other construction details prevent full coverage or packing. Careful pre-inspection and extra drill holes are usually required.	Easily identified triangular voids above one or both corners.
Central mid-wall voids on 1st floor	Inadequate attention or poor technique can lead to poor packing. Balloon frame walls were blown from one drill hole at top of second floor. The insulation gets hung up on nails, fin stops, or cross bracing.	Distinct image specific to one stud cavity. More common with glass fibre.
Jogs, corners, or junctions of partitions with exterior walls	Construction details make insulation difficult. Occasionally a complete stud space will be missed (e.g. narrow, unsuspected cavities that can only be detected if the contractor first probes and measures the adjoining cavity).	Blurred streaky images complicated by framing, air leakage, and the cold corner effect.
Special construction details (bay windows, fireplaces, stairwells, additions, hatches, boxed-in-corners)	The most distinguishing trait between houses was attention to detail. This can vary between crews, contractors, or even as a result of whether or not the householder stays home and shows concern.	Identification will depend largely on thermographers' expertise.
Exposed floors (such as floors beneath baywindows, cantilevered 2nd storeys, coldroom ceilings, garage ceilings, third floor dormers, porch or vestibule floors).	Many older houses have exposed floor areas that could be easily and profitably insulated at the same time as the wall cavities with blown insulation.	Very obvious cold patches.

qualitative tool, it is difficult to assess whether the magnitude of air leakage into wall cavities was affected by the insulation. However, it was apparent that floors and partition walls had significantly more cold air patterns after insulation relative to the exterior reinsulated walls. This may suggest a reduction in air leakage rates through exterior wall cavities as a result of reinsulation.

3. A brief thermographic evaluation is provided in Table 3 on a house-by-house basis. In general, the quality of insulation work was extremely good, with better than 95% coverage in all the test houses. It is too early, of course, to detect problems due to splitting or settling of insulation within the wall cavities. It should also be noted that contractors were aware that tests were to be conducted; it is impossible to know to what extent this affected their performance.

4. There was no noticeable variation in quality or coverage due to the specific contractor or to the type of insulation. Problems detected in each house were more likely due to structural details which posed difficulties, or which were poorly understood by the contractor. Some insulation crews are definitely more innovative and determined than others when trying to ensure comprehensive coverage.

In the more unique or complex building structures, there is considerably more effort required by the contractor. Current cost estimation procedures rarely reflect the extra work involved in coping with many small structural details and the result is that insulators tend to ignore such work unless the householder shows concern and stays at home during the installation. Ideally, contract specifications should identify these important features, and the techniques to be employed. The CGSB training materials and insulation contractor certification program could also benefit from a more detailed examination of how structural anomalies affect insulation application techniques.

TABLE 3: HOUSE BY HOUSE THERMOGRAPHIC EVALUATION

Waverley House Contractor A Wall Insulation 137m^2 Cellulose 30 bags @ 13.6 kg. $890	Overall coverage was excellent, with good attention to special details. The bay window area in living room defied attempts by insulators due to the thickness of building materials. Clean-up was thorough and customer satisfaction high.
McLaren House Contractor B Wall Insulation 225m^2 Glass fibre	Fair coverage with a number of significant voids remaining in this house. The balloon construction in this house appeared to have a larger than normal number of braces and studs. Areas next to corners, fireplace and above windows were especially bad.
Fifth Ave. House Contractor C Wall Insulation 109m^2 Attic insulation 56m^2 Total cost Cellulose 30 bags @ 13.6 kg. Cellulose 20 bags @ 13.6 kg. $730	Good coverage of the walls and attic in this house with no major voids and good attention to details around openings. An inexplicable mottled pattern appeared over much of the wall surface. Attic hatch was left untouched (very leaky and poorly insulated). Relatively more defects existed in the rear addition (which had been insulated previously by occupant).
Shakespeare House Contractor A Wall Insulation 152m^2 Ceiling Insulation 53m^2 Total Cost Cellulose Cellulose $1690 67 bags @ 13.6 kg.	Overall the insulation coverage was fair in the walls with a few poor details over windows and doors. Attic insulation depth and coverage was excellent. House continues to be exceptionally leaky due to a panelled wall finish that leaks at every joint. To ensure a trouble-free insulation job the contractor could have first arranged with the householder to have the walls sealed.

Third Ave. House Contractor B Wall Insulation 150m^2 Glass fibre	Fair to good insulation coverage in this house. A small void remains in the living room wall and a number of voids above doors and windows. Considerable amounts of air leakage into the wall cavities and around windows shows an urgent need for airtightening.
Besserer House Contractor A Wall Insulation 140 m^2 Total Cost Cellulose $820 45 bags @ 13.6 kg.	Good wall insulation coverage in this house. A number of small defects (crimps, gaps, leakage) were present in the attic and in the extensions but these areas had been previously insulated with batts by occupant. Air leakage throughout the house is excessive. Wall condensation problems are likely, especially in view of the high insulation levels, the low average indoor temperatures, and the high average indoor humidity levels.
Second Ave. House Contractor B Wall insulation 137m^2 Attic insulation 55m^2 Glass fibre $1,600 37 bags @ 17 kg.	Excellent insulation coverage in this house with no voids and good coverage around windows and doors. Insulation job included a well insulated and quite tight attic hatch (at the householder's request). The 150 mm thick balloon frame walls probably contributed to good packing in stud spaces along 1st storey. Depth and coverage of attic insulation was excellent.
Strathcona House Contractor A Wall Insulation 92m^2 Cellulose	Overall a good insulation job in this house. No voids were apparent in cavities that were insulated. The contractor did a poor job of exploring the more unique areas of the house. The floor in bay extension of second floor over veranda uninsulated floor should have been checked and insulated. The basement ceiling should have been blown full of insulation where it extends out under front porch. The attic requires additional insulation at north and south extremes where the coverage gets much thinner (this area had been insulated previously, but could have been checked at the time of job estimation).

5. Batt insulation would appear to be more likely to experience problems than loose fill when used as a retrofit material. Most of the houses included in this study incorporated wall or ceiling areas that had previously been insulated with batt insulation. These areas showed a higher incidence of insulation defects, air leakage and moisture problems than the areas insulated as part of the study.

4.2 Discussion on Test Procedure

The pre-insulation thermographic scan did not reveal much information about the house. It was hoped that it would be possible to detect the specific structural details of the exterior wall cavities (e.g. firestops, diagonal bracing, extra studding) and in this way map out a preferred reinsulation strategy. In actuality, this was not possible. Even with the best quality infrared equipment, there is fairly poor camera resolution, and unpredictable thermal patterns over the walls tend to confuse or obscure structural details.

From this limited amount of testing, it would appear that the only value to a pre-insulation thermographic scan is in the identification of air leakage sites, or for the identification of specific building components that could be blown full with insulation as part of the wall job (e.g. uninsulated dormers, inadequately insulated addition walls, overhangs and exposed floors, inaccessible roofs, and attic problem areas).

The post-insulation thermographic scan proved to be a very useful component of this study and is, in general, an excellent quality control mechanism. However, some question still remains as to the value of wall thermographic scanning for the average householder. A thermographic report typically costs $150. In the case of this study, such a service could not have provided much value to the householder, since many of the anomalies or inadequacies are not large enough to warrant a return visit by the contractor. A more useful approach for householders would be a scan conducted by the contractor immediately following reinsulation. The contractor could use a low-cost videocon scanner, since there would be no requirement for high resolution or hard copy images.

Probably the best use of thermographic equipment is in evaluation and training exercises where insulation crews can receive useful feedback about problems created by wall structural details in the local housing stock.

Air leakage accounted for the vast majority of meaningful thermal images in these test houses. From the perspective of the thermographic evaluations, it would have been preferable if the houses had been air-tightened (caulked and sealed) prior to, or in conjunction with, the wall reinsulation. A reduction in air movement images would make it easier to identify voids and condensation problems in the homes (i.e. problems relating directly to the insulation job). And the thermographic scan could function as an evaluation tool for the air-tightening work as well.

An infra-red scanner was found to be particularly well suited to the location of air leakage sites and pathways in the sample houses. One of the most positive aspects of combining the thermographic with air-tightness testing is the synergistic effect of the "door fan" (depressurization apparatus used to locate leaks and measure equivalent leakage area). The negative pressure created by the door fan accelerates air leakage into the house, thereby enhancing the contrast and "visibility" of any thermographic images. Moreover, the door fan operation ensures that all air leakage is infiltration. Otherwise, somewhere between one third and one half the air leakage would consist of warm air leaking out of the house (or exfiltration). Exfiltration is impossible to "see" with the infra-red scanner, since there is no temperature difference; it also serves to partly warm the building envelope and confuse the thermal image by making cavities and building materials appear warm, regardless of their thermal resistance. As a general rule, infra-red analysis of housing is best combined with the use of a door fan. Other field testing using the combined technologies has also shown good results(2).

The thermographic evaluation of insulation work did not require high temperature differences across the building envelope because of the combined use of the door fan. However, there was still a noticeable improvement as the temperature differences increased. During the initial testing of the housing, homeowners were asked to turn off their heating system two or three hours before the test

appointment, so as to avoid thermographic images from the heat distribution system. This procedure was eventually reversed with very good results. Householders were asked to slightly over-heat their homes for several hours before testing was to commence. In this way, the temperature difference was increased between indoors and outdoors, leading to improved imagery. Moreover, the induced air leakage from prolonged door fan operation would be less likely to cool the house to uncomfortable temperatures.

The operation of the heating system immediately prior to scanning did not appear to confuse the thermographer or prevent a comprehensive evaluation of wall reinsulation.

A fan depressurization test was conducted as part of the pre- and post-insulation investigations on all eight test houses. A Retrotec Door Fan was employed for this purpose. The tests were conducted in accordance with the third draft of the CGSB standard 14 A GP 10 (3).

The CGSB standard expresses airtightness of housing in terms of Equivalent Leakage Area (ELA) at 10 Pascals. An ELA is roughly equivalent to the size of the hole a house would have if all the leaks were gathered together. The ELA is calculated from the air flow at 10 Pascals (as measured with the door fan equipment) using a multiplier of 1.157. A more detailed explanation of the ELA calculations can be found in the CGSB standard.

The air flow/air pressure relationship in houses is approximated by the equation $Q = C*P^n$

Where: Q = Quantity of air flow in m^3/s
C = Constant for the house
P = Indoor outdoor pressure difference in Pascals
n = An exponent (determining the rate at which the air flow changes with pressure)

The test data were analysed to give values of C and n for the house, and those were used to calculate the air flow through the house at a constant pressure difference of 10 Pascals.

5.1 Results

1. An airtightness test report and air flow pressure profile for each house is included in Appendix 2.

   A complete survey of air leakage sites was conducted in conjunction with the airtightness testing. The results are summarized on the air leakage checklists shown in Appendix 3, which pinpoint leakage sites for each house.

A summary of the airtightness test data is presented in Table 4. Some of the test highlights are described below.

The average Equivalent Leakage Area (ELA) at 10 Pascals was .26 m^2 before reinsulation and .18 m^2 after reinsulation, for an average reduction of 22%.

Two of the test houses, Waverley and Third Ave., indicated a marked increase in ELA following reinsulation. Both these houses are suspected to be anomalies caused by changes in the size of the area under test in the pre- and post-configurations. The Waverley house did not have an inspection of partition doors during the pre-test; it is likely that the door to the leaky third storey was shut. The Third Ave. house has a leaky sunporch that was completely sealed during the pre-test. To permit access by the insulators, the sunporch was opened up; it was left unsealed during the post-test. If these two houses are disqualified, the average reduction in leakage area becomes 33%. In either case, the change in ELA suggests a surprisingly large reduction in air infiltration characteristics solely as a result of wall reinsulation.

2. A survey of air leakage sites conducted with smoke pencils indicated that the houses had a large number of leaky areas and that there was no apparent change in leakage patterns as a result of insulation. The wall leakage sites included outlets, switches, floor trim, window and door casings and mouldings around fireplaces. Many other leakage sites were also connected to the exterior wall cavities through more circuitous routes (e.g. stair risers, floor boards, and partition walls). Both the air leakage survey, and the ELA data, suggest that the wall cavities in these houses function as major conduits for air movement into and out of the house.

TABLE 4: AIRTIGHTNESS TEST SUMMARY

	HOUSE CHARACTERISTICS					PRE-INSULATION						POST INSULATION						PERCENT CHANGE	
	Area m^2	Vol. m^3	Heat. Syst.	Fire-plce	Win-dows	C	n	ELA m^2	Rel. ELA cm^2/m^2	Air Flow m^3/s	Air Change per Hour at 50 Pa.	C	n	ELA m^2	Rel. ELA cm^2/m^2	Air Flow m^3/s	Air Change per Hour at 50 Pa.	ELA at 10 Pa %	AC/h at 50 Pa %
1. Waverley	376	790	oil water	YES	D.H.	.118	.625	.20	5.3	1.37	6.2	.118	.723	.25	6.7	2.00	9.7	+25	+46
2. McLaren	363	706	oil air	YES	D.H.	.301	.520	.39	10.7	2.30	11.7	.142	.642	.24	6.6	1.75	8.9	-38	-24
3. 5th Ave.	240	500	oil air	NONE	D.H.	.076	.778	.16	6.6	1.47	10.6	.056	.81	.14	5.8	1.20	8.6	-13	-18
4. Shakespeare	225	307	oil water	NONE	SLID ALUM	.085	.645	.15	6.7	1.06	12.4	.056	.664	.10	4.4	.75	8.8	-33	-29
5. 3rd. Ave.	267	543	oil air	YES	D.H.	.109	.507	.14	5.2	.79	5.2	.117	.516	.15	5.6	.88	5.8	+7	+11
6. 2nd Ave.	240	432	oil air	NONE	D.H.	.221	.576	.33	13.8	2.10	17.5	.131	.585	.20	8.3	1.30	10.8	-39	-38
7. Besserer	290	531	gas air	YES	D.H.	.335	.569	.50	17.2	3.11	21.0	.101	.770	.24	8.3	2.06	14.0	-52	-34
8. Strathcona	180	328	oil air	YES	D.H.	.150	.555	.21	11.6	1.31	14.4	.153	.512	.14	7.8	1.15	12.6	-29	-12
AVERAGES	272	517				.17	.60	.26	9.6	1.69	12.4	.11	.65	.18	6.7	1.38	9.9	-22	-12.3

3. It is significant that, in all but one case, the 'n' value (or exponent) increased significantly for the test houses following reinsulation. The average pre-test exponent was 0.595 and the average post-test exponent was 0.653.

The exponent contains useful information about the air leakage processes, and a short discussion would be useful at this point. When air leaks into a house, it first has to pass through small cracks or openings in the wall exterior, then through the fairly large cavities in the wall, then through small cracks or openings in drywall or other finishing. Airflow through small cracks or openings is characterized by an exponent that is close to 0.5. Airflow through wall cavities is characterized by an exponent that is close to 1.0. Therefore, if the airtightness test produces an exponent that is close to 0.5, this indicates that the various small openings and cracks govern the rate of air leakage through the house envelope. If loose-fill insulation is put in the wall cavity, it will create further resistance to the leakage of air through the building envelope. This resistance is characterized by an exponent that is close to 1.0. The airflow resistance presented by the cracks and openings, together with the resistance presented by the insulation, therefore result in an exponent that is somewhere between 0.5 and 1.0. If the actual exponent is somewhere around 0.7 to 0.8, this means that the insulation is playing a significant part in controlling air leakage. The airtightness tests in this study show that, in all houses except one, the exponent was increased by the addition of insulation. This gives indirect theoretical support to the idea that insulation tends to increase the airtightness of a house.

4. Partly as a consequence of the increased exponent, the effect of the insulation tends to become more pronounced as the test pressure decreases. In normal operation, the pressure difference across the house envelope is usually in the range 0 to 5 Pascals. Therefore, the effect of the insulation, under normal household circumstances, would be more pronounced than is indicated by the changes in ELA at 10 Pascals (Table 4).

5. It is interesting to compare the reduction in ELA as a result of reinsulation with reductions obtained by weatherizing houses using caulking, sealants, and weatherstripping. In the winter of 1981/82, a weatherize study was conducted by Retrospectors and sponsored by the Ontario Ministry of Municipal Affairs and Housing[4]. The 15 weatherized test houses were somewhat newer and smaller than the houses in this study, and the average pre-tightening ELA was .24 m^2. After sealing windows, basement, trim work and attics, the ELA's were reduced to .13 m^2 (average) for an overall reduction of approximately 40%. This reduction is not much greater than has been achieved in these test houses through reinsulation alone.

6. The possible effect of insulation on airtightness raises the question of energy savings, and to what extent these are being double-counted. If a reduction in "ELA" size corresponds to a reduction in natural infiltration rates, the reductions in this sample of houses could translate into a fuel saving in the order of 7 to 12 percent. (If approximately 33% of total heat loss is attributable to air change, the calculation would be .22 x 33 or .33 x 33). For this reason, any further efforts at measuring energy savings from wall insulation should be conducted on houses that have first been airtightened. It would be unwise to attribute air infiltration reductions to insulation work if these savings can first be obtained through safer, and possibly more cost-effective, sealing procedures.

7. The interpretation of airtightness test data assumes that the test method is a relatively accurate ($\pm$5%) and repeatable measurement of airtightness. In this study there was only one attempt to repeat a test on a house without changing its configuration of the home. Appendix 2 includes a second post-insulation test on the Third Avenue house. Both tests showed identical air flows, and ELA's, regardless of a two week interval between tests, and changes in wind speed, direction and temperature.

8. The Air Tightness Test Summary (Table 4) includes a measurement of ELA (cm^2) per square meter of building envelope (above grade). It is obvious from

reviewing this table that this normalized measurement is much preferable to the size of the ELA (m^2) as a means of comparing the leakiness of the houses. Both the size of house and the size of the ELA can, and do, vary significantly. Only after allowances have been made for the envelope area does it become clear that Second Ave. (a small house) is in fact a very leaky house.

9. The tests houses included homes with brick veneers, wood siding and stucco. The two houses with predominantely stucco veneers (Shakespeare and Strathcona) would presumably have had less air leakage through the walls, with a correspondingly smaller reduction in air leakage area as a result of reinsulation. However the reduction in ELA for these houses is close to average; it is possible that the stucco is by-passed in so many locations that its effects on air tightness are minimal.

Indoor relative humidity and temperature was monitored for a period of several weeks before and after the re-insulation work. An analogue hygrometer * was mounted on an interior partition wall, close to the household thermostat. Householders were very co-operative in recording humidities and temperatures twice daily (usually as they adjusted the thermostat settings).

6.1 Results

A summary of average indoor air temperature and relative humidities for all the test houses is presented in Table 5. These averages are based upon recordings over a five day period immediately prior to insulation, and a five day period following. Recordings were made over a longer period of time in most cases. Day-by-day readings for each house are tabulated in Appendix 4. The highlights from the data are summarized below.

1. The indoor temperature data does not change significantly as a result of reinsulation, (although this may not be the case in "colder" parts of the house). The average temperatures correspond fairly well with the estimates given by householders in their energy audit interviews, but only after corrections are made for inaccuracies in the household thermostat.

* These hygrometers proved to be accurate within 2% and very responsive to minor changes in R.H. Hygrometers were calibrated using a wet towel procedure and then verified on-site using an automatic psychrometer.

TABLE 5: RELATIVE HUMIDITY AND TEMPERATURE READINGS

TEST HOUSES	PRE-INSULATION (5 DAYS BEFORE)		POST-INSULATION (5 DAYS AFTER)		RELATIVE HUMIDITY
	TEMP (C)	% R.H.	TEMP (C)	% R.H.	CHANGE IN % R.H.
Waverley	18.3	32.8	17.9	39.6	6.8
McClaren	19.8	36.6	20.0	35.6	-1.0
5th Ave	19.9	34.0	20.0	35.4	1.4
Shakespeare	19.2	38.5	16.3	40.0	1.5
3rd. Ave.	19.3	35.1	20.6	38.1	3.0
Besserer	17.4	35.1	17.8	40.0	4.9
2nd Ave.	17.2	42.2	17.2	51.6	9.4
Strathcona	12.3	43.4	19.0	46.2	2.8
AVERAGES		37.2		40.8	3.6

2. The average R.H. increased in all but one house following reinsulation. The average R.H. before insulation was 37.2%. After insulation this increased to 40.8%.* Increased humidities indoors may be a result of reduced air change and a build up of moisture from normal household activities.

3. The change in average R.H. is not large enough to indicate a definite relationship for all cases. Although R.H. remains fairly constant in most houses over a 2 to 3 day period, it is not uncommon to see changes of 4% R.H. to 5% R.H. over longer periods of time.

   Some houses are noticeably more constant than others, with a total fluctuation of less than 3% R.H. In other houses the R.H. can be seen to jump as much as 7% in one day.

   To establish a definite relationship it would be necessary to record humidities indoors and outdoors on a continuous basis and over a longer period of time. Over a short period of time there may be unpredictable movement from clothes drying or bathing. Even the effect of the insulation materials would have to be considered, since cellulose insulation, may actually dry the house initially by sponging moisture from the building components.

* No attempt has been made to correct these changes for changes in outdoor humidities. However temperature outdoors averaged below -5°C and the amount of moisture in the outside air is not likely to have changed considerably.

4. In three of the test houses, there was a very significant increase in R.H. following insulation. Two of these houses, Besserer and Second, incorporate greenhouses within the living space, including 5 to 10 m^2 of planting beds. Both houses also had the highest R.H. to begin with. This suggests that R.H. is a sensitive measurement of air tightness only in houses where there are large and constant sources of moisture production. In other words, a house with low relative humidity that is suddenly tightened in wintertime may not experience a sudden increase in the indoor humidity since the absorbent buffer of the building materials may be sufficient to compensate for the reduction in ventilation rates.

Furnace efficiency measurements were conducted on three occasions: before insulation, after insulation and after the system had been serviced and tuned. The first two tests were conducted by a technician using a RAB Dedesco electronic furnace efficiency meter; the final test was conducted by a burner mechanic using a conventional Bacharach kit. The instrumented tuning involved primarily an adjustment of chimney draft and the combustion air intake. The servicing of the furnaces entailed a thorough cleaning of heat exchanges and fans, a lubrication and control check and the completion of an inspection report that has been incorporated into the energy audit. There was no nozzle down sizing.

7.1 Results

A description of each heating system and a summary of furnace efficiency testing data have been presented in Table 6.

1. The pre-insulation and post-insulation efficiencies varied less than 2%. This variation is not more than would normally be expected from changes in such variables as location of probe, length of warm-up time, cold starting or hot starting, and variations in chimney draft due to wind and temperature.

2. The change in efficiency due to servicing and tuning of the units was, on average, 12.5 * percent. This is clearly a significant improvement that demonstrates the value of a careful, instrumented tuning for oil furnaces. It is not known to what extent this increased efficiency of operation is likely to deteriorate with time.

* Note: Increases in furnace efficiency are calculated according to the following equations:

$$\text{PERCENT CHANGE} = \frac{(\text{post test} - \text{pre-test})}{\text{pre-test}} * 100$$

TABLE 6: HEATING SYSTEM DESCRIPTION

HOUSE	TYPE OF SYSTEM	FIRING RATE (USGPH)	AGE (YRS)	EXPECTED LIFE SPAN (YRS)	TEST PERIOD*	EFFICIENCY TESTING DATA				
						DRAFT ("H_2O) **	SMOKE NO.	CO_2 (%)	STACK TEMP. (°C)	EFFIC. (%)
WAVERLEY	Warden King Boiler Lennox Oil Burner Forced Hot Water	1.35	30-35	3-5	Pre	.07	-	6.4	324	67.0
					Post	.075	-	5.8	318	63.5
					Tuned	Retention Head Burner Installed				80.0
McLAREN	Brock Oil Furnace Forced Warm Air	.85	5	10-20	Pre	.05	-	7.6	300	72
					Post	.06	-	7.8	322	71
					Tuned	.02	2	9.0	204	83.0
FIFTH AVENUE	Grimsby Furnace Aero Oil Burn. Forced Warm Air	.85	10	10	Pre	.03	-	Not Available		
					Post	.04	-			
					Tuned	.04	-	7.6	229	77.1
SHAKESPEARE	Oil Burner Vicking Boil.	.80	30	5-10	Pre	.04	-	5.6	288	66.7
					Post	.03	-	5.5	268	68.0
					Tuned	.01	2	6.5	191	78.0
THIRD AVENUE	Forced Warm Air Esso Oil Furnace	-	20	3-5	Pre	.05	-	7.6	321	71.0
					Post	.02	-	7.0	260	74.0
					Tuned	.02	2	9.5	204	84.0
BESSERER	Inter-City Gas Forced Air	N/A	3	15-20	Pre	.05	-	7.3	238	78.5
					Post	.05	-	7.8	254	77.0
					Tuned	-	N/A	6.5	149	82.0
SECOND AVE.	Clare Hecla Oil Furnace Forced Warm Air	.85	18	3	Pre	.03	-	7.8	258	75.2
					Post	.06	-	6.6	260	72.5
					Tuned	1.5	3	7	204	80.0
STRATHCONA	Brock Forced Air Oil	-	5	10-20	Pre	.06	-	9.3	279	78.0
					Post	.06	-	9.6	292	76.6
					Tuned	.01	3	11.5	260	82.5

* Test periods were pre-insulation, post-insulation and after the unit was tuned and cleaned.

** Testing equipment was calibrated in non-metric units. To convert "H_2O to Pascals multiply by 249.

3. The servicing and tuning of the furnaces was conducted after the completion of energy monitoring so as to avoid distorting the measured impact of wall re-insulation. However, in the evaluation of yearly fuel consumption records it will be necessary to allow for improvements to the estimated seasonal operating efficiencies. This was unavoidable since the furnace inspection and tuning was part of the energy audit package offered as an incentive to householders considering participation in the study. The increased steady state efficiency must be balanced off against lower seasonal efficiencies from shorter average run times, (see ENERGY MONITORING).

4. It is interesting to note that the older furnaces had been operating at relatively lower efficiencies prior to tuning. After tuning, however, the efficiencies appeared fairly constant amongst all the units, regardless of age.

Indoor wall and ceiling surface temperatures were recorded on a single occasion before and after reinsulation of each house. Surface temperatures were taken at a central location on each wall for each storey of the building, at distances 300 mm above floor level, 1500 mm above floor level, and 300 mm below the ceiling level. Ceiling temperatures were taken in three locations across the ceiling.

Surface temperatures were made in identical locations on both tests by means of numbered location stickers temporarily attached to the wall surface. Indoor air reference temperatures were taken at distances approximately 300 mm away from each surface location. Temperatures were recorded by means of an I.M.C. digital thermometer with a thermistor probe on a thermally isolated handle. The thermometer has a response time of 30 seconds, an accuracy of $\pm$ .1°C, and was calibrated on-site to ensure consistent accuracy.

8.1 Results

The temperature differences between wall surfaces, and indoor and outdoor air temperatures have been tabulated for each house in Appendix 6. These tables also contain conductance values for each test point before insulation and after insulation and the ratio between the two. The conductance values have been converted into RSI Values by using the known resistance of the air surface film, (RSI .113). These RSI Values are presented in Table 7 and compared against the predicted or theoretical RSI Values calculated using standard CGSB values for the specific building structure and insulation material.[5] Ceiling values have also been measured and calculated where attic insulation was installed at the same time as wall insulation.

The wall surface temperatures vary considerably for each test house. However the average measured RSI Values for the uninsulated walls and ceilings are in fairly close agreement with theoretical predictions. After insulation the agreement is generally very poor. In many cases wall surfaces are relatively cooler after insulation than before, and the effect of insulation becomes insignificant.

It would appear that large amounts of warm air leakage and mixing in wall cavities are distorting the conventional model of horizontal heat flow across the walls. Instead, what becomes apparent is that wall surface temperatures are more related to air flow patterns than to the thermal resistance of building materials.

The wall surface temperatures close to the ceiling are commonly much warmer (relative to the surrounding air) than the wall surface temperatures in the middle, * suggesting degrees of temperature stratification within the wall cavity. (For detailed temperature and location data refer to Appendix 5.)

Wall surfaces may also become cooler as wind speeds increase; this relationship is illustrated by the data presented in Table 8. It would seem likely that wall surfaces would be relatively cooler along the windward wall then along leeward walls, but no such relationship is apparent from the data. Nor is it possible to see any immediate relationship between the location of the neutral pressure plane and the wall surface temperatures. (Neutral pressure planes were located at the same time as the surface temperature measurements took place.)

* It is probable that surface temperatures close to the floor would be colder still, but most of these areas remain warmer because of the insulating qualities of the high wood baseboards.

TABLE 7: THEORETICAL AND MEASURED RSI VALUES FROM WALL RE-INSULATION

HOUSE	NO. OF TEST POINTS	PREDICTED RSI		MEASURED RSI*	
		PRE	POST	PRE	POST
FIFTH	WALLS 12	1.0	3.3	1.09	1.44
	ATTIC 3	2.5	5.6	2.58	2.28
SHAKESPEARE	WALLS 24	0.8	3.1	1.0	**
	ATTIC 3	2.2	5.6	1.6	
THIRD AVENUE	WALLS 39	1.0	2.3	1.18	**
BESSERER	WALLS 18	1.0	3.3	3.40	3.65
SECOND AVE.	WALLS 24	1.0	2.7***	1.54	1.20
	ATTIC 3	2.2	7.6	1.47	0.82
STRATHCONA	WALLS 18	1.0	2.3	.766	0.919

* EQUATION FOR RSI VALUE DETERMINATION: $RSI = .113 \times \frac{T\ INDOOR - T\ OUTDOOR}{T\ INDOOR - T\ SURFACE}$

** EQUIPMENT FAILURE DUE TO STATIC ELECTRICITY

*** WALL CAVITY IS TYPICALLY 100 mm (WITH LUMBER SHEATHING BOTH SIDES), EXCEPT FOR SECOND AVENUE WHERE CAVITY IS 125 mm.

TABLE 8: WALL SURFACE TEMPERATURES AND WIND SPEEDS

HOUSE	PRE/POST	T AIR - T WALL* (°C)	WIND SPEED (km/h)
FIFTH	PRE	3.6	26
	POST	2.2	11
BESSERER	PRE	1.5	4
	POST	2.6	20
SECOND	PRE	2.0	9
	POST	2.5	30
STRATHCONA	PRE	4.2	22
	POST	3.0	11

* TAIR - T WALL refers to the temperature difference between the wall surface and the surrounding air.

Discussion of Test Procedures

A number of difficulties were encountered in attempting to obtain rapid, accurate surface temperatures:

1. It was very difficult to isolate the effects of the warm air distribution system in the house. Fan and furnace had to be shut off well before testing.

2. The thermistor probe had to be applied to the wall surface for several minutes in several locations before it became possible to lower its mass temperature and accurately record each test point temperature.

3. The wall surfaces close to the ceiling required the technician to reach upwards with the probe and this action was sufficient to distort the readings by sending currents of warm air up the body and sleeve and into the vicinity of the test point.

4. The constant touching of the (ungrounded) probe to various surfaces in a dry old house naturally led to problems with static electricity. On two occasions the unit had to be sent back to the U.S. manufacturer for the replacement of the electrically damaged components.

The neutral pressure plane across each face of each test house was located before and after the reinsulation. Initially the existence of negative or positive pressures were detected with a null pressure indicator (tubing attached to a flexible plastic container). The pressure taps consisted of short pieces of 13 mm tygon tubing routed directly across the wall through window openings packed with strips of closed cell foam. The tubing extended outside approximately 75 mm and was capped with a wind screen and dampening device. The technique was later refined with the use of a Validyne pressure transducer connected to a strip chart recorder. The strip chart recorder permitted the technician to visually average the pressure over a period of time. With two such measurements at different heights on one face of the building it is possible to plot a pressure profile and precisely locate the neutral pressure plane.

Eventually it proved adequate to simply use a smoke pencil around wall cracks, window frames or areas established as leaky during a depressurization test, and to determine whether the smoke flowed out of, or into, the building. This approach can usually locate neutral pressure to within a meter, and is much less time consuming.

All locations identified during these tests were taken with the furnace turned off.

9.1 Results

The neutral pressure plane locations have been presented in Table 9. The location of neutral pressure is in the range of 4 to 6 metres above grade for most houses. The location corresponded to the upper portion of the second storey windows in a 2 storey house, and somewhat higher in 2-1/2 storey houses. The temperature difference across the envelope was similar during both testing periods.

Wind speeds and directions changed, but there was no evidence of increased suction (i.e. a higher N.P.P.) on the lee side. Even low winds speeds cause a considerable amount of pumping of air due to vortices. The neutral pressure zone is more accurately described as the location where air moves in and out in equal quantities. Only for very brief periods of time can the pressure difference across the walls be considered to be zero.

TABLE 9: NEUTRAL PRESSURE PLANE LOCATIONS

HOUSE	PRE-INSULATION						POST-INSULATION					
	T_{in}-T_{out}	WIND (km/h)	N.P.P. Ht ABOVE GRADE(m) N	W	S	E	T_{in}-T_{out}	WIND (km/h)	NN.P.P. Ht ABOVE GRADE(m) N	W	S	E
FIFTH	34.2	N@26	5.5	5	5	N/A	28.5	WNW@11	6.0	5.6	5.2	N/A
THIRD	35.2	W@26	2nd floor windows							2nd floor windows		
BESSERER	24.9	W@4	6.7	6.7		5.0-6.2	28.0	ENE@20	5.4	5.9	5.0	6.0
SECOND	28.5	WNW@9	-2.7m	2.7	2.7	2.7	26.3	ENE@30	4.1	3.5	4.5	4.2
STRATHCONA	32.2	NW@22	6.0	5.3	5.0	N/A	28.7	WNW@11	4.8	5.0	4.8	N/A

NOTES: Data are not available for all houses because of equipment malfunction.
N/A refers to a wall without windows and doors.

9.2 Discussion of test design

More continuous monitoring of the pressure profile across the building envelope is necessary before any conclusions can be made regarding the effect of wall re-insulation. If insulation has significantly tightened the walls, there would tend to be a shift upwards. In theory the less frequent cycling of furnaces would tend to shift the pressure plane downwards. The net effect of these forces may be insignificant over time; especially in light of the large and variable forces of wind and temperature.

An effort was made to measure the effect of furnace operation on the location of the neutral pressure plane in a number of the test houses. In large houses (e.g. Waverley) the effect was insignificant. In smaller houses there may have been a shift upwards but the movement was highly erratic and difficult to measure without more sophisticated equipment.

A decay heat loss measurement was conducted on each test house before and after wall insulation. Thermocouples connected to a two channel strip chart recorder were used to continuously monitor indoor and outdoor temperatures. The equipment was set up in the evening and householders were requested to turn their thermostat well down before going to bed and to keep the house temperature as warm as possible for comfort before that time. Internal heat gain over night was estimated and energy time constant calculations were performed according to established procedures.(6)

A time constant for a house corresponds to the time required for the temperature difference between indoors and outdoors to be reduced by approximately two thirds (2/3).

The equation for time constant is as follows (from reference 6):

$$t^* = \frac{t}{\ln \frac{(RQ/A)-(T_r-T_o)}{(RQ/A)-(T-T_o)}}$$

Where
- t^* = time constant
- t = elapsed time in minutes
- R = building resistance (RSI)
- Q = heat to house from all sources (.i)
- T_r = inside temperature at start (°C)
- T_o = outside temperature (°C)
- A = area of building envelope
- T = instantaneous inside temperature

The building resistance factors were taken from the energy audit calculations for pre-insulated and post-insulated loads. Heat gains (Q) during the decay were estimated as follows:

- residents @ 125 W (reference 6)
- lighting and appliances at 400 W before 12:00 PM
  100 W after 12:00 PM
- furnace fan (Fifth Ave. only) at 250 W continuous

10.1 Results

The results of the energy time constant calculations are presented in Table 10. Decay heat loss data has been tabulated and plotted for each house in Appendix 6.

Complete time constant tests for before and after insulation have been presented for four test houses only. The test procedure was under development while some houses were undergoing insulation, and although all houses were tested prior to insulation, not all of the data were valid.

TABLE 10: ENERGY TIME CONSTANTS

TEST HOUSE	t*(Hours) PRE-INSULATION	t*(Hours) POST INSULATION	% CHANGE
FIFTH	37.0	71.4	93
THIRD	20.8	44.4	113
SECOND	29.2	28.0	-4
BESSERER	24.4	26.3	8

It is difficult to interpret the energy time constant data because of the experimental nature of the test, and the small sample size. In 3 out of 4 houses the time constant was noticeably longer after insulation. The extent to which these changes are a measurement of the insulation effectiveness is yet not clear. Without knowing the specific thermal mass of the houses it is impossible to know the extent to which the time constant is dependent upon the thermal resistance.

All the houses appear to have long time constants even before insulation. These older houses incorporate a considerable amount of thermal mass because of the large amount of plaster and masonry building materials. Even in Ottawa's coldest winter weather it would take more than a full day of no heat for the indoor temperature to reach freezing.

The sample includes houses with several outstanding anomalies. The Fifth Ave. house is semi-detached; the shared wall possibly explains the exceptionally long time constant. The Besserer home began its post-insulation test with a very low indoor temperature of 12.9°C (the occupants would not agree to warming the house prior to the decay) and this made measurement difficult. The Second Ave. house had installed a large number of planting beds with fluorescent fixtures, and it is impossible to estimate the impact of these additional heat gains on the before and after decay rates.

In any case both the Second Ave. and Besserer houses displayed relatively little change in the time constants compared to the Third and Fifth Ave. houses where the time constant actually doubled after insulation. Such a major incongruity in the data suggests that the time constant is being strongly affected by variables other than insulation.

One very interesting result of the decay heat loss testing was the nature of the temperature/time profile for the houses. In all cases the houses would cool quickly until the temperature dropped 4°C. At this point it was possible to see a reduction in the cooling rate as the thermal mass within the house began to lose significant amounts of heat to the indoor air.

The initial temperature drop would, under normal circumstances, be sufficient to cause the furnace to turn on and re-heat the house. (A typical thermostat span is 2°C). The amount of heat required to heat the house at that time will be in proportion to the mass of air in the house, since this will be heated up in the same quick fashion that it cooled. Consequently, it can be said that a furnace will become more efficient (i.e. run continuously for longer periods) as the volume of the house is increased. In this sense, the actual design heat load of the house is of little relevance in predicting seasonal efficiency. Rather, furnaces become more or less efficient in relation to the volume of the heated space.

10.2 Discussion of the Test Procedure

The decay data and log-linear graphs contained in Appendix 6 illustrate the effect of outside temperature on the time constant values. The time constant is not readily apparent until calculated. The calculations are a tedious affair, especially when the temperature data must first be transposed from the voltage readings on the strip chart recorder. There is definitely a need for a more refined, digital procedure for monitoring the decay heat loss rate, and a software package needs to be developed for the calculations.

The night-time testing worked very well considering that it allowed the houses to cool sufficiently without discomfort to the occupants. It is also easy, in most cases, to estimate or monitor any extraneous heat inputs at night while the house cools. The cooling curves indicate that the houses cool quickly, as the air temperature drops 3 to 5°C during the first 45 to 60 minutes. After that time, the second time constant begins as the thermal inertia of the mass within the structure slows down the cooling. An accurate estimate of this slower cooling rate is usually possible within a 2 to 3 hour period, which suggests that the test itself can be a fairly quick and easy procedure.

In the future such decay heat loss measurements should incorporate the use of a portable, programmable solid state thermostat. It is too risky and complicated to leave the control of the furnace to the householders during the test period. Ammeters and event recorders could also be used to more accurately monitor additional heat inputs from appliance use or fan operation.

The use of energy time constants based upon decay heat loss may prove to be a very effective method of quickly gauging the impact of retrofit measures on existing housing. More experimentation is required to refine testing techniques and to test the sensitivity of the measurements. Further analysis and experimentation is currently underway in Ottawa as part of the performance testing of houses in the Apple Hill subdivision, sponsored by the Canada Mortgage and Housing Corporation.[7]

A more appropriate test technique would likely involve the use of co-heating (with electric resistance coils) and the maintenance of a steady state temperature within the house. If a door fan could be used, at the same time, to provide a constant air change rate and normalize the infiltration losses, it should be possible to measure the conductance value of the house directly, both before and after reinsulation.

Energy consumption rates in all test houses were monitored for a period of one to two weeks before and after wall insulation. In addition two "reference" houses were monitored continuously to provide a base case to compare against the before and after rates of re-insulated houses.

Energy consumption was monitored by means of 4 channel event recorders connected to the oil burner and to the circulation pump or fan. In this way it became possible to measure total on-time and furnace cycling over any period of time, and to calculate average continuous run times (i.e. the average length of one run) for both the burner and the heat distribution system.

The use of "reference" houses was intended to be an elegant means of correcting furnace on-time data for variables such as wind speeds and hours of sunshine. Because the test house and the reference house are exposed to identical weather conditions, it is reasonable that the ratio of furnace on-time between the houses should remain constant over time. Any variation in this ratio following re-insulation should be a direct indication of energy savings.

Results

The average daily on-time per degree day, the average daily on-time ratio between test and reference houses, and the average continuous run times for all test houses are presented in Table 11. The percentage change in energy consumption based on monitoring data is also presented in Table 11. More detailed data for each house can be found in Appendix 7.

The results indicate a clear reduction in energy requirements for the test houses in all cases where sufficient data were available to make such comparisons. The reductions in on-time per degree day were highest in two houses where both walls and attics were insulated (Fifth and Second), averaging 37 percent. Complete data are available for two houses with wall re-insulation only, with a reduction of 6 percent. There is also a marked reduction in average furnace run times before and after insulation, with an average reduction of 30 percent.

TABLE 11: FURNACE ON-TIME RATIOS AND AVERAGE RUN TIMES

Test Houses	PRE-INSULATION						POST-INSULATION						CHANGE	
	Record Days	Avg. Daily On-Time Per Degree Day In Hours	S.D.	Avg. Daily On-Time Ratio (Test/ Ref)* In Hours	S.D.	Avg. Continuous Run Time in Minutes	Record Days	Avg. Daily On-Time Per Degree Day In Hours	S.D.	Avg. Daily On-Time Ratio (Test/ Ref) In Hours	S.D.	Avg. Continuous Run Time in Minutes	% Change On-Time Per Degree Day	% Change In Avg. Run Time **
WAVERLY	1	N/A	0	N/A	0	15.1	3	.270	.012	1.06	.024	9.8	N/A	-25
McLAREN	4	.224	.029	1.17	.085	2.1	7	.211	.022	1.49	.499	1.7	-6	-19
[illegible]	7	.113	.008	.756	.004	6.7	7	.093	.019	.880	.521	1.75	-18	-75
[illegible]														
[illegible]	4	.129	.015	.849	.135	2.5	4	.122	.015	1.34	.954	2.0	-6	-20
[illegible]	5	.117	.042	.594	.239	10.3	6	.053	.016	.465	.220	8.8	-54	-15
[illegible]	1	.129	0	.914		N/A	-	-	-	-	-	-	-	-

* This is the average daily on-time of the test house divided by the averaged daily on-time of both reference houses.
** The average run times include the long run period required for morning warm-up.

The standard deviations for daily on-time per degree-day or per reference on-time are quite high in most cases, indicating a need for longer monitoring periods or more control over the house operation. The standard deviations are much worse when test house furnace on-time is compared to the reference houses than when the comparison is against weather office degree days.

The fact that the reference houses were not kept at a constant temperature, coupled with variations in lifestyles, probably account for the excessive scatter.

The high reductions in average run times are difficult to understand without consideration of the large temperature set-backs in these houses overnight and, in some cases, during working hours. A brief discussion is warranted here, so as to explain better the monitoring data.

The temperature set-backs cause considerable cooling of the thermal mass in the house - to a degree determined by outdoor temperature and the thermal resistance of the envelope. The uninsulated houses become colder, and consequently require a much longer warm-up cycle after set-backs to overcome the thermal inertia of the building.

Without such set-backs there would likely be a less significant change in average run-times. The thermal mass in the house would remain at a fairly constant temperature, with the furnace primarily heating only the mass of air in the house. This effect has been noticed in the decay heat loss data.

In an un-insulated house, there would theoretically be more frequent cycling of the system, (since the air is losing heat more rapidly through un-insulated walls), but the average run time would remain fairly constant because the furnace is heating a constant amount of air over a constant temperature rise. The data in Table 11 show how much this is not the case for real houses where temperatures can fluctuate considerably. As a result, the impact of furnace cycling on seasonal performance efficiencies may be considerably worse for houses that have undergone re-insulation.

11.1 Discussion of Test Procedures

The energy monitoring methods employed for this stu
were experimental in nature. The objective was to devel
a rapid, accurate and cost effective technology f
measuring effects of conservation practices and retro
measures on the energy requirements of housing.

For a number of reasons it was difficult to obtain usef
data for this study regardless of the techniques. T
weather in Ottawa in March was excessively warm a
unpredictable. The equipment was untried and in most cas
did not work as intended due to operator unfamiliarity
faulty design. And the project was very rushed due
understandably impatient householders and a very tig
project schedule.

The experience of monitoring on-time in the test houses c
provide some insights into what might constitute a mo
effective procedure. The most important (albeit obviou
lesson is the need for more control over the variable
indoor temperature and occupancy.

One means of reducing occupancy variables is to exclu
from the monitoring periods Saturdays, Sundays or holida
of any sort.

Another possibility is to monitor during specific periods
the day. A 24 hour timer can easily be connected to t
event recorder, and set to record operation during the nig
for example, when solar gain is eliminated, and when
other variables are fairly constant. However, many of t
test houses required virtually no furnace input at all ov
night because of temperature set-backs.

A better approach may be to run the event record
constantly, but to control indoor temperature precisel
This can be done by use of a programmable solid stat
thermostat (such as the Enerstat) that can be temporari
slung over the existing thermostat and attached to t
terminals with alligator clips. This system allows f
constant and accurate control of indoor temperatur

throughout the monitoring period. Thermostatic control in an occupied house has been recently implemented for purposes of energy time constant testing with excellent results.(7)

Time and cost savings can also be made by eliminating the strip chart recorders. It is possible to connect miniature 24 VAC pulse counters and time totalizers* to the same thermostat leads so as to obtain detailed digital recordings of total operating time and number of cycles. Occasional reading of these counters by householder or technician during the monitoring period provides sufficient data from which to establish energy consumption rates and average run times. The technology itself would cost less than $180., including counters and thermostat. Unlike a strip chart recorder, such counters would not require a furnace mechanic for installation.

The four channel strip chart event recorders employed in this study created considerable frustration due to installation difficulties. Initially the recorders were installed so as to take up the roll of chart paper by re-winding the paper into the machine. The paper (a 20 metre roll) tended to jam occasionally and in this way ruin all of the data. A better approach is to let the paper feed out on to the floor.

Difficulties or time delays were also encountered when wiring the event recorder to the oil burner in those cases where the furnace had no stack relay switch. Gas furnaces required an additional 24 volt relay switch to operate the 110 VAC recorder; the relay switches are expensive, difficult to wire, and in some cases will not work (due to insufficient amperage or electronic ignitions).

* For example, consider the Hecon or Cramer digital counters listed in mail order catalogues available from Electrosonic.

If strip chart event recorders can be operated properly th
do offer considerable flexibility and convenience as
energy monitoring technology. Transfering the data fro
the strip charts is a fairly rapid task when using engineeri
calipers, and provides accuracies of ± 0.38 mm. If the ge
ratio is 25 mm per hour it becomes possible to measu
furnace operating time with errors of less than 1/2 minu
over a full day. The strip chart will also present a minut
by minute description of operation - allowing the analyst
choose the most appropriate periods of time for t
purposes of the study. And the 4 channels perm
simultaneous monitoring of circulating pumps and fans, h
water heaters and other appliances. At 25 mm/h a sing
chart will last a month.

The lack of constant relationships between reference hous
and test houses suggests that reference houses must
carefully choosen and operated with programm
thermostats. The initial heat load of both test a
reference houses should be very similar to avoid proble
from non-linear degree day relationships. The houses shou
have a similar amount of exposed, south facing glazing
ensure equal solar gains and roughly the same number
occupants to ensure similar internal gains. In this way
should be possible to compare on-time rates regardless
weather conditions.

If a number of such houses could be continuously monitor
in each community, sophisticated modeling of weather da
may not be necessary. A simple comparison of ratios cou
provide anyone in the region with a reasonably accura
estimate of energy savings. Estimates could be made wi
high levels of confidence within a period of no more th
eight days following the conservation measure.

Energy audits were conducted on all test houses using the model "ECAP" procedure recently developed by Sebastian Moffatt and Ron Argue for the Enhanced Conservation Assistance Program (ECAP) of Energy Mines and Resources Canada.[8] For comparison purposes the computerised "Enersave" Class B audit currently offered by EMR was also completed on each test house.

The inclusion of the audit in the current study was designed to:

(1) permit comparison of savings prediction techniques with measured energy savings;

(2) permit comparison of the results of EMR's "Class A" (on-site) ECAP audit procedure now under development with the current "Class B" computerized mail-in system (The ECAP audit in some cases uses slightly higher minimum R-values than Enersave but uses the Enersave cost estimate system directly);

(3) offer comprehensive energy conservation advice to participating householders as a lever to encourage participation;

(4) to collect basic data on each house (e.g. volume, component areas, heating plant data, general inspection of existing insulation and sealing conditions).

Results

The ECAP and Enersave audit recommendations summary for each house is provided in Appendix 8. The main results of the audit work are outlined below. (A more detailed assessment is underway as part of the ECAP program development).

(1) Measured Verification of Predicted Savings - Unfortunately, due to problems with the event recorder monitoring system, accurate values for fuel savings were available for comparison on four houses only. The measured savings have been compared with the predicted savings in Table 12. In three out of four houses the energy audit predictions were significantly higher than the actual savings. However, the experimental nature of the energy monitoring technique does not permit even tentative conclusions about why it was not possible to achieve a better agreement.

Any discrepancy between actual savings and predicted savings is most likely due to the considerable indeterminency which exists in weather and economic variables and key energy use factors such as air change rates, free heat gains, effective RSI-values and seasonal efficiency. (Suggestions to better account for these variables, based in part on the performance of the ECAP audit on the eight test homes, are currently being prepared by Argue-Moffatt for EMR audit managers).[9]

It is worth noting that current work by Argue-Moffatt on ECAP audit development suggests that the accuracy of audit savings predictions is more likely to be at the level of correctly weighting the relative savings between optional measures rather than in precisely determining savings in absolute terms.

(2) Comparison of ECAP and Enersave Predictions - The predicted energy savings for wall insulation from both the ECAP and Enersave audit systems (both recommend RSI 2.1) are shown in Table 13. A striking feature of the comparison is that the ECAP savings, which are based on actual fuel records, are 2 to 3 times lower than the Enersave predictions which are based on a theoretically derived heating bill (ASHRAE method).

To explain the discrepancy between the two systems, Table 13 also compares the ratio of the savings estimates with the discrepancy between ECAP projected fuel cost estimates based on actual fuel records versus the theoretical ASHRAE heat load predictions.

TABLE 12: COMPARISON OF MEASURED FUEL SAVINGS VERSUS PREDICTED FUEL SAVINGS

HOUSE	AREAS INSULATED	MEASURED FUEL SAVING	PREDICTED FUEL SAVING
McLAREN	WALLS	6%	23%
THIRD	WALLS	6%	28%
SECOND	WALLS & ATTIC	54%	28%
FIFTH	WALLS & ATTIC	18%	27%

TABLE 13: WALL SAVINGS PREDICTION COMPARISON

HOUSE	WALL INSULATION SAVINGS AS PERCENT OF FUEL BILL ECAP	ENERSAVE	SAVINGS RATIO ECAP/ENER$AVE	RATIO OF ECAP FUEL CONSUMPTION ESTIMATES ACTUAL/ASHRAE*
WAVERLEY	16	52	.31	.38
McLAREN	23	100 (sic)	.23	.32
FIFTH	23	45	.51	.58
SHAKESPEARE	40	42	.95	.52
THIRD	28	86	.32	.43
BESSERER	32	not recommended	-	.35
SECOND	24	57	.42	.52
STRATHCONA	27	38	.71	.70

* The ECAP analysis provides energy advisors with a comparison of the predicted annual fuel consumption for the next complete heating season (based on ACTUAL fuel records provided by households) versus a theoretical prediction derived from ASHRAE heat load analysis.

The direct and close correlation between the two ratios indicates that most of the discrepancy between the two audit systems is due to the fact that the ASHRAE method used by Enersave overestimates the actual heating load by a factor of 2 to 3. It would appear that the ASHRAE system may grossly underestimate effective R-values and free heat contributions for vintage housing stock.

In any event, the Enersave system would appear to consistently overestimate savings.* It is also interesting to note the Enersave cost estimation system (upon which the ECAP costs estimates are also based) predicted wall insulation costs which commonly were 50-100% higher than actual costs. This may be due to economies related to the low end of the insulation season and from combining wall insulation and attic insulation work in some cases.

As a final point, it was noted during the ECAP client interviews that householders occasionally report inaccurately on their house, which would lead to errors in the mail-in Enersave system that would be avoided with an on-site system. For example, one householder reported that the upper level of the main part of her home was inaccessible and uninsulated whereas it actually was accessible and contained about 4 inches of insulation.

* To avoid gross savings errors, the Enersave system is designed to limit predicted savings to 65% of the reported fuel bill. This limit does not apply to particular categories of work, but only to the total predicted savings. Consequently houses with limited opportunities for reinsulation may receive gross over estimates of savings without reaching the 65% limit. In one case where the limit did exceed 65%, the limit could not be applied because the reported fuel bill was above the highest range in the Enersave questionnaire.

(3) Advice Package - The general advice delivered to each participating householder is as shown on the ECAP results summary form - Appendix 8. The audit pinpointed improvements for the domestic hot water system, weatherstripping and caulking requirements and additional insulation requirements. Heating system recommendations included thermostat setback savings opportunities, and heating system improvements via circulating fan setting reductions (or addition of a circulating pump in one case), installation of solenoid valves, and nozzle downsizing. Large efficiency improvements were actually achieved in most homes by the tuning and cleaning functions which were performed by the Retrospectors burner mechanic. Normally this work would have been recommended with savings predictions of 10%.

It should be noted that theoretical calculations indicated that if all insulation recommendations were completed in each home, the furnaces would all be left oversized by a factor of 2 to 3. However, downsizing recommendations were based on existing insulation levels, and generally limited to only one size below the existing level. Downsizing more than one size could risk problems of poor air mixing and low efficiency, unless the furnace is equipped with a retention head burner. The householder was advised to discuss downsizing first with their regular serviceman.

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POOR

QUALITY

ORIGINAL